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SeaWiFS global land data set for 1997-2002

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Abstract: Daily daytime SeaWiFS 4-km global area coverage data have been processed to produce an **4.63-km** equal-area data set from September 1997 through May 2002 for all continents except Antarctica. Features of the data set include SeaWiFS lunar calibration, 16-day composities, and atmospheric correction for Rayleigh and ozone effects. Data fields available include the normalized difference vegetation index and the enhanced vegetation index; surface reflectances at 412 nm, 443 nm, 555 nm, 670 nm, and 875 nm; solar zenith angle, zenith view angle, and view azimuth angle; and the date of each pixel. Preliminary evaluation of the channel reflectance data indicates a high degree of stability from desert targets of ± 1-2% surface reflectance variation over the entire SeaWiFS record of almost 5 years. This data set has been processed to be a "match up" data set to MODIS, with 16-day composites and a multiple of the MODIS spatial resolution. All data are available from the NASA/Goddard Distributed Active Archive Center and from the University of Maryland Global Land Cover Facility.

Background

Satellite data are indispensable for quantitative understanding of atmosphere, oceans, and land processes. While Landsat, SPOT, Earth-Observer-1, Ikonos, Quickbird, and other higher spatial resolution satellites provide multipsectral land data at 4-30m, these data are not globally available on a daily basis and are restricted to smaller areas at discrete times. It is doubtful if satellite sensor data with spatial resolutions < 250 m will be globally available in the near future, due to very large data volumes. For example, daily 250 m data from MODIS available globally comprise ~ 20 gb per channel per day uncompressed. Consequently, coarse-resolution satellite data, available daily globally at spatial resolutions of 500 m to 4 km, provide the only ability to quantitatively record land processes through time (Table 1).

New, improved, coarse-resolution global land satellite data are available from sea viewing wide field of view sensor (SeaWiFS) (October 1997 – present), SPOT-4's Vegetation Sensor (May 1998 – present), and NASA's moderate resolution imaging spectrometer (MODIS) on the Terra platform (January 2000 – present). These data compliment 1981-2002 data from the advanced very high resolution radiometer (AVHRR) instruments which have flown on several National Oceanic and Atmospheric Administration polar-orbiting meteorological satellites (Table 1). This paper describes a new coarse-resolution satellite data set of the land surface which has been produced from the Sea viewing Wide Field of view Sensor (SeaWiFS).

SeaWiFS instrument

SeaWiFS is an 8-channel visible and near infrared scanning filter radiometer designed to measure earth-exiting spectral radiances from oceans for the purpose of determining oceanic primary production. SeaWiFS is the only scientific payload on the Orbital Sciences Corporation's Sea Star spacecraft. Because of its oceanic pigment sensing mission, the SeaWiFS instrument was designed to have 8 narrow spectral bands, a wide-field-of-view ($\pm 58^o$), a coarse spatial resolution of 1.1 km at nadir, a high sensitivity to a wide range of spectral radiances, maintain a high level of absolute on-orbit radiometric calibration, and image the earth tilted 20^o from nadir along track (Barnes et al., 1994) (figure 1; table 2). SeaWiFS "tilts" from a viewing position looking aft 20^o or forward 20^o from nadir in the along-track direction to avoid sun glint over water. The Sea Star spacecraft orbits the earth in a sun-synchronous orbit at 705 km altitude. Equitorial crossing times are noon and midnight and the orbital period is 100 minutes. No data are acquired at night.

A feature of the SeaWiFS instrument is its bilinear or "split" gain (figure 2). This is necessary to provide very sensitive data from oceans, where low magnitude water leaving radiances are the norm, and also from land, where deserts, snow, and dense green vegetation in the near-infrared have high reflectances.

The SeaWiFS instrument collects data for ~40 minutes each descending daytime orbit, where the solar zenith angle is < 75^{o}. This results in ~ 75^{o} of latitude being imaged every orbit. The SeaWiFS instrument tilts to avoid sun glint from the ocean surface, tilting from 20^{o} aft along track prior to the sub-solar point of the orbit for that day, to a forward tilt of 20^{o} along track after passing the sub-solar point. A 20^{o} tilt from nadir at the SeaWiFS orbital altitude corresponds to ~3^{o} latitude at nadir. The time to accomplish the change in tilt is ~13-14 seconds. As SeaWiFS' velocity is 7 km sec^{-1}, ~500-600 km of data are lost on each orbit due to the tilting maneuver (2^{o} aft to 2^{o} aft, both along track, plus ~100 km during tilting) (figure 3). These data are not recoverable. To minimize the loss of data from the same region, the latitude of initiation for tilting is varied every other day by 2^{o}. This results in the zone of data loss varying over a wider range of latitudes (figure 4). The coverage for any given day can be viewed on the SeaWiFS Mission Operations web site (http://plankton.gsfc.nasa.gov/sched/).

The SeaWiFS sensor was designed to facilitate atmospheric correction while being highly calibrated through time. This is necessary for "ocean color" instruments, where spectral radiances at the top of the atmosphere contain 90% atmospheric effects and only 10% is water-exiting radiance. These same design, atmospheric correction, and calibration considerations make SeaWiFS an excellent source of data from the land surface.

On-orbit or vicarious calibration is achieved through the measurement of the instrument's black interior by every scan coupled with scanning the moon surface every lunar cycle. The combination of these calibration approaches results in high degree of radiometric accuracy through time (Barnes et al. 2001 and Eplee et al. 2001).

SeaWiFS data processing

SeaWiFS global data are transmitted from the satellite and received at the SeaWiFS project at NASA/Goddard and converted to a level-0 format. Each SeaWiFS level-0 file contains 6-8 orbits of image data, the satellite global positioning system data, and the attitude sensor data.

Each orbit within the level-0 file is next processed to a separate level-1a **HDF** file. The processing to level-1a includes removal of highly erroneous lines (based on bit-error analysis), filtering and fitting of global positioning system orbit data, and interpretation of attitude sensor data. The orbit, attitude, and sensor tilt are then combined to produce line-by-line geolocation information, which is stored in the level-1a file along with the raw image data and dark offset data.

Each level-1a file is then processed to level-2. The first step in that process is the conversion of the image data from uncalibrated digital counts to calibrated radiances. This includes the subtraction of the dark current offset, the conversion from digital counts to radiance, and the correction for temperature, scan modulation, and mirror-side effects. The lunar-based correction for time-dependent changes in detector sensitivity is also applied. The level-2 SeaWiFS data are then calibrated spectral radiances.

The calibrated radiances are then combined with the geolocation information, which is interpretted at each pixel to yield longitude and latitude, sensor view zenith, sensor azimuth, solar zenith, and azimuth angles. The radiances, geolocation, and path geometries are then provided to the atmospheric correction routine, which converts the radiances to surface reflectances. Based on a dilated land mask, pixels which are not within 25 km of land, coastline, or ephemeral water are returned with a surface reflectance of zero (EVI and NDVI set to -2).

The computation of surface reflectance includes corrections for gaseous and diffuse transmittance, Rayleigh path radiance, and atmosphere-surface interaction (spherical albedo). The derived surface reflectance at each SeaWiFS wavelength is written to a level-2 HDF file, along with the geolocation and path geometries, and the EVI and NDVI values derived from the surface reflectances. The NDVI and EVI are calculated as:

$$\text{NDVI} = \frac{(\text{channel } 8 - \text{channel } 6)}{(\text{channel } 8 + \text{channel } 6)} \quad (1)$$

$$\text{EVI} = \frac{2.5(\text{channel } 8 - \text{channel } 6)}{(\text{channel } 8 + 6*\text{channel } 6 - 7.5*\text{channel } 2 + 1)} \quad (2)$$

where channel 6 = 660-680 nm and channel 8 = 845-885 nm.

For each day, the set of 14-16 relevant level-2 files which bracket the day in question are passed to the Level-3 land binning program, which effectively maps all scans for the day in question to a 4.6-km sinusoidal output grid. Multiple daily observations for the same grid cell size are resolved by selecting the minimum view zenith angle for the day in question.

To produce 16-day composites, the relevant set of daily files are processed using a hybrid minimum-blue/maximum-NDVI algorithm to select the best observation within each 4.6-km bin to include in the composite. The 16-day composite data are then projected into the desired map projection and bundled into HDF files.

SeaWiFS data compositing

A new temporal compositing technique has been developed to produce 16-day vegetation indices and corrected reflectance products. Daily grided vegetation indices and corrected reflectance products are generated for each day of a compositing period, 16-day periods in our case. Under normal conditions over 16 days, each location on Earth is observed at least 8 days at the equator and up to 16 days at at latitudes above or below 50^{o}. For each compositing period, one of the daily observations of each pixel of the globe is selected to generate the composite product. The selection criterion is designed to maximize the spatial coherence of the composite product. This approach is based on previous studies demonstrating the usefulness of the coherence as an indicator of the quality of a composite product (Pinzon et al. 2001). Maximizing the coherence significantly decreases the occurrence of compositing artifacts, such as the presence of clouds, cloud shadows, or snow in the composite product.

The maximum-coherence technique is based on the analysis of the results of two well-known compositing techniques - the maximum-NDVI and minimum-blue criteria - consolidated with spatial homogeneity tests in the near-infrared band. Results verify that the spatial coherence of the individual bands and the derived vegetation indices in the composited products is significantly increased with this new technique, compared to those obtained with the traditional maximum-NDVI and minimum-blue techniques. This indicates a much better resistance to compositing artifacts, and consequently this technique provides a much more adequate way of selecting land surface properties representative of a 16-day period. The important point to keep in mind is that excellent vegetation indices are produced and, at the same time, excellent channel reflectance data as well.

General overview of SeaWiFs land data

The SeaWiFS land data produced exhibited a high degree of channel reflectance, NDVI, and EVI stability through time (figure 5). This is to be expected, following the emphasis in the SeaWiFS project on calibration (Barnes et al. 2001).

We found a greater sensitivity for the NDVI than the EVI for areas of dense vegetation (figure 6), contrary to assumptions in the literature (Huete et al. 1997). This was the case in areas of dense green vegetation, ranging from tropical forests, to sub-tropical savannas during the growing season, to Eastern US deciduous forests, and boreal forests. A likely reason for this is the extremely high correlation between the 443 nm and 670 nm SeaWiFS reflectance channels (figure6). Perhaps narrow-band satellite data which have been atmospherically corrected for Rayleigh scattering and oxygen abosorption and then formed into composite images do not benefit from the EVI vs. the NDVI. In any case, the very high correlation between the 443 nm and 670 nm SeaWiFS reflectance channels for areas of dense green vegetation suggests no benefit from the EVI. Another possibility is the “ad hoc” nature of the EVI, with the various coefficients (see equation 2), is not suited to SeaWiFS data. The NDVI, in contrast, seems to be of value in spite of its simplicity.

Artifacts are introduced into the SeaWiFS data from “tilting”. These take of the form of missing data in the “tilt” region, if the zone of tilting is not varied. The combination of the unavoidable loss of data near the equator from “tilting” (see figures 3 and 4) coupled with high cloud cover in some areas, results in serious cloud-tilt contamination some areas (figure 7). This problem is made worse by the the absence of thermal channels on SeaWiFS, which makes cloud detection more difficult. We suggest taking the approach of Los(1998) to overcome these minor problems in SeaWiFS data.

Data formats

All continental parameters are stored in a single file , each file represents a 16 day compositing period, with a spatial resolution of 4.63 km in a sinusoidal map projection. All data, except Julian Day number, are stored as 16 bit scaled integer in an HDF4.1r3 format. All metadata are stored as individual HDF global attributes. The Browse images are in jpeg format (Table 4). All global climate modeling parameters are stored in a single file with each file representing a monthly compositing period. The spatial resolution is 0.25 degree (about 28 km at equator) and all arrays except Julian Day number are stored as 16 bit scaled integer in the HDF 4.1r3 file format. All metadata are stored as individual HDF global attributes and the browse images are in jpeg format (Table 5).

Quality Assurance

We have employed several methods to check the quality of the SeaWiFS land data described in this paper. We implemented an automated technique based upon spatial coherence after Pinzon et al. (2000) (figure 8). Each of the zones indicated in figure 8 had their spatial coherence computed which was summarized in the output file. Areas of bad data were identified, either by a sharp peak in the spatial coherence text value or a dip in the same index, depending upon circumstances (figure 9). We reviewed each image manually to understand the automated spatial coherence results.

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Table captions

Table 1. Table 1. Global coarse-resolution satellite spectral vegetation index data sets

Table 1. Global coarse-resolution satellite spectral vegetation index data sets.

Instrument	Dates of Coverage	Spatial Resolution (nadir)	Spectral Bands	Global Data Volume (gb/day)	References
NOAA AVHRR	7/1981-present	4-km	5	0.6	Cracknell 1997; Kidwell 1999
SeaWiFS	9/1997-present	4-km	8	0.4	**???????????**
SPOT-4 Vegetation	05/1998-present	1-km	4	3.2	**???????????**
MODIS	01/2000-present	250-1000 m	32	70	**???????????**

Table 2. Characteristics of the SeaWiFS instrument. While SeaWiFS was designed to measure chlorophyll concentrations in the oceans, it also maintains measurement sensitivity over bright land targets. The SeaWiFs orbit is sun synchronous at an altitude of 705 km and results in equator crossing times of noon ±20 minutes. The nadir spatial resolution is 1.1 km and 4.5 km with associated swath widths of 2800 and 1500 km, respectively. Radiometry is digitized at 10 bits. Table extracted from Hooker et al., 1992. Spectral bandwidths are given at the 50% spectral response levels. Bands 1, 2, 5, 6, and 8 are included in our SeaWiFS land data set (see also figure 1).

Band	Bandwidth (nm)	Saturation radiance$_1$	Signal:noise ratio
1	402-422	13.6	499
2	433-453	13.3	674
3	480-500	10.5	667
4	500-520	9.8	640
5	545-565	7.4	596
6	660-680	4.2	442
7	745-785	3.0	455
8	845-885	2.1	467

$_1$units of mW cm^{-2} μm^{-1} sr^{-1}

Table 3. Data layers and characteristics of the global SeaWiFS land data set.

PRODUCT	ARRAY DIMS(X x Y)	SIZE (MB)	FILES / YEAR
NDVI	4800 x 4800	46	23
EVI	4800 x 4800	46	23
Day	4800 x 4800	46	23
Rfl412	4800 x 4800	46	23
Rfl443	4800 x 4800	46	23
Rfl555	4800 x 4800	46	23
Rfl670	4800 x 4800	46	23
Rfl875	4800 x 4800	46	23
Sol ZA	4800 x 4800	46	23
Sat ZA	4800 x 4800	46	23
Rel AZ	4800 x 4800	46	23
Browse	TBD	TBD	24

Table 4. Continents, dimensions, and data volumes of the global SeaWiFS land data set.

PRODUCT	SENSOR	PARM	ARRAY DIMS(X x Y)	SIZE (MB)	FILES / YEAR	MB / YEAR	YEARS	TOTAL (GB)
AFRICA	SEAWIFS	All (11)	1680 x 1920	74	23	1702	3	5.1
ASIA	SEAWIFS	All (11)	2160 x 2160	107	23	2461	3	7.4
AUSTRALIA	SEAWIFS	All (11)	1440 x 960	32	23	736	3	2.2
EUROPE	SEAWIFS	All (11)	1200 x 1200	33	23	759	3	2.3
N. AMERICA	SEAWIFS	All (11)	1920 x 1680	74	23	1702	3	5.1
S. AMERICA	SEAWIFS	All (11)	1200 x 1920	53	23	1219	3	3.7
TOTALS						14191		132.5
Global CMG	SEAWIFS	4	1440 x 720	7.3	12	88	3	0.3
Browse	SEAWIFS	1	TBD	TBD	12	TBD	3	TBD

Note: SeaWiFS Global CMG product contains only EVI, NDVI, and QA flag while the SeaWiFS continental product contains NDVI, EVI, DAY, Ch 1(412 nm), Ch 2 (443 nm), Ch 5 (555 nm), Ch 6 (670nm), Ch 8(875 nm), solar zenith angle, view zenith angle, and the relative azimuth.

Table 5. Metadata for continental products**.** The table below lists the granule-level metadata in the HDF files for the continental data products which are stored as HDF global attributes.

ATTRIBUTE	DESCRIPTION	FORMAT
Product Name	Filename of Granule	string
Title	Descriptive name for product	string
Data Center	Site of Data Production	string
Satellite	ORBVIEW-2	string
Sensor	SeaWiFS	string
Product Version	Version number of product granule	string
Product Generation Date	Date product was generated (YYYY/MM/DD)	string
Software ID	Algorithm name, version # used to create data	string
Ancillary Input Files	List of N ancillary files used	N strings
Period Start Date	Begin date of granule (YYYY/MM/DD)	string
Period End Date	End date of granule (YYYY/MM/DD)	string
Start Time	Begin time of granule (HH:MM:SS)	string
End Time	End time of granule (HH:MM:SS)	string
Map Projection	Map Projection name and attributes	string
UL Corner Point	Latitude, Longitude of upper left corner in deg	2 reals
UR Corner Point	Latitude, Longitude of upper right corner in deg	2 reals
LL Corner Point	Latitude, Longitude of lower left corner in deg	2 reals
LR Corner Point	Latitude, Longitude of lower right corner in deg	2 reals
Grid Resolution	Grid resolution in km	string
NPIXELS	Number of pixels (x direction) in grid	integer
NROWS	Number of rows (y direction) in grid	integer
NLAYERS	Number of parameters (separate arrays)	integer
Overall Quality Rating	Quality description	string
Geolocation Filename	Name of associated geolocation file	string

Figure captions

Figure 1. Spectral response functions of the 5 bands in the SeaWiFS global land data set. See table 1 for information on the 8 SeaWiFS bands.

Figure 2. Bilinear gains of the 5 bands in the SeaWiFS global land data set.

Figure 3. SeaWiFS 4.5 km imagery from May 29, 2002 illustrating the data lost on each orbit from changing the along track "tilt" from 2^{o} aft to 2^{o} forward in close proximity of the sub-solar point. The change in "tilt" takes ~13 seconds to accomplish. "Tilt" is necessary to minimize sun glint over oceans, as the primary mission of SeaWiFS is ocean color remote sensing. Approximately 500-600 km of data are lost during the change in "tilt".

Figure 4. Two SeaWiFS 4.5 km orbital segments from different days over a portion of North Africa and Arabia illustrating how the "tilt" zone is varied to avoid loss of data in

the same geographical area. The latitude where “tilt” is initiated varies at 2-day intervals within a range of $\pm 4^{o}$ of latitude. See also figure 3.

Figure 5. Examples of SeaWiFS data from the Sahara Desert over time from an area located at 23-25 ^{o} N by 28-30 ^{o} E. (A) Reflectances of SeaWiFS bands 2,5,6, and 8 have a small range over their time period. (B) Normalized difference vegetation index and enhanced vegetation index from the same channels in (A). Note the small range in the vegetation index data over five years.

Figure 6. SeaWiFS land data from an area in the Amazon located at 0-2 ^{o} N by 60-66 ^{o} W. (A) Normalized difference vegetation index and enhanced vegetation index and (B) a plot of the 443 nm channel vs. the 670 nm channel from the same area as (A) and (C) an area of boreal forest in Newfoundland. The almost perfect correlation of the 443 and 670 nm channels suggests the enhanced vegetation index loses sensitivity by incorporation of the blue band into the enhanced vegetation index. Similar results which show an unexpected greater sensitivity in the normalized difference than enhanced vegetation index have been found for a wide range of densely vegetated areas.

Figure 7. Examples of artifacts present in the SeaWiFS land data set. (A) loss of data over Central and South America from day 193 to day 208 of 1999; (B) Unavoidable presence of clouds in 16-day composite imagery with a few areas with no data from day 161 to day 176 of 1999; and (C) Interaction of data lost to “tilt” and high cloud cover over tropical South America for day 097 to day 112 of 1999 results in a reduced number of cloudless data which can be included in data composites. SeaWiFS’ lack of thermal channel(s) makes detection of clouds more difficult